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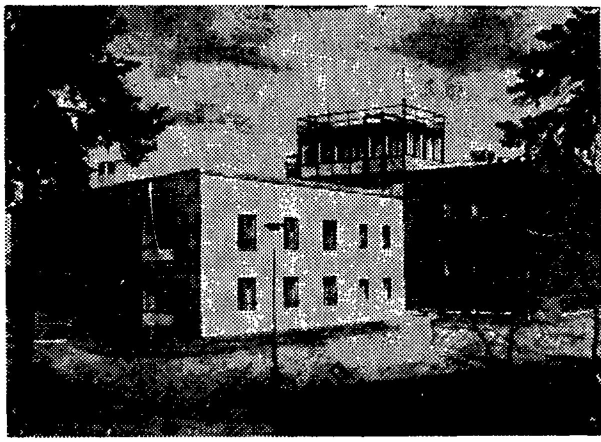

A SYSTEM FOR AUTOMATIC COLLECTION AND PROCESSING OF STANDARD MAGNETOMETER DATA, AND THE CALCULATION OF THEIR POWER SPECTRUM

by

G. GUSTAFSSON, A. THUNBERG and K.-E. HEIKKILÄ
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Kiruna C, Sweden

Annual Summary Report
Contract No. AF 61(052)-237

Report period 1 October 1961 - 30 November 1962
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TABLE OF CONTENTS

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ABSTRACT

The equipment which is under construction for collection of the geomagnetic data, will sample all three components of the earth's magnetic field each 30 seconds. It has been completed and tested for recording of one component and found to be working satisfactorily. In the near future recordings will also be made of the other two components.

A computer program has been developed for the reduction of the data.

An analyses has also been made of the spectrum of the fluctuations of the geomagnetic X-component in the frequency range $0.5 - 4.2 \cdot 10^{-4}$ cps.

Purpose of contract work

1. Set up and operate equipment to provide for the direct digitalization of measurements of the Y and Z components of the geomagnetic field and make the necessary arrangements for the later inclusion of 70 mm variable-area recorders for these components.
2. Compute hourly, daily and monthly averages of the measured magnetic field components and of the delta values of magnetic activity and furnish promptly tables of these quantities.

I. Equipment

1. Introduction

The digitaly recording equipment for one component of the earth's magnetic field, described in detail by Hultqvist et. al. (1961), was carefully tested during the last year. The timing unit was in continuous operation as well as the film recording. Due to the development work on the equipment which has been going on during the year the data was recorded in digital form only during limited parts of the period. In the months October and November 1962 continuous digital records were made to test the computer program. A block diagram of the equipment is shown in Fig. 1.

The present situation is that the equipment has been completed and found to be satisfactory for the recording of one component. Detailed plans have been made for extension of the apparatus to record all three components, and some preparations for this have been made.

2. Changes and Improvments Made in the Equipment.

The servo system used for regulation of the current in the compensation coils of the magnetometer has been carefully adjusted to obtain optimum frequency response. The response curve on the higher frequency section can be seen in Fig.2, which shows the response of the magnetic detector itself, without the servo system. The curve for the whole system is shown in Fig. 3. The calibration was made by means of a sinusoidally varying field, applied near the detector by a bar magnet, mounted as a torsion pendulum. It can be seen from the calibration that it is possible to compensate for the resonance, which occurs at a period of 4 seconds, by adjustment of the servo system to give an almost flat frequency response also for the high frequency part of the spectrum.

It was found that the digital voltmeter used (see Hultqvist et. al., 1961) does not function properly in the voltage ranges 0. 992 to 1. 00 volts and 9. 92 to 10. 0 volts. The decimal point change mechanism of the voltmeter operates continuously if the signal is in either of these voltage ranges, and the trigger signal for the punch does not function.

The reason for this behaviour is internal noise in the voltmeter which was found to be very difficult to eliminate. It turned out that it was easiest to change the voltage range supplied by the millivolt recorder to the digital voltmeter (cf. Hultqvist et. al., 1961) so that it did not involve the voltage ranges mentioned.

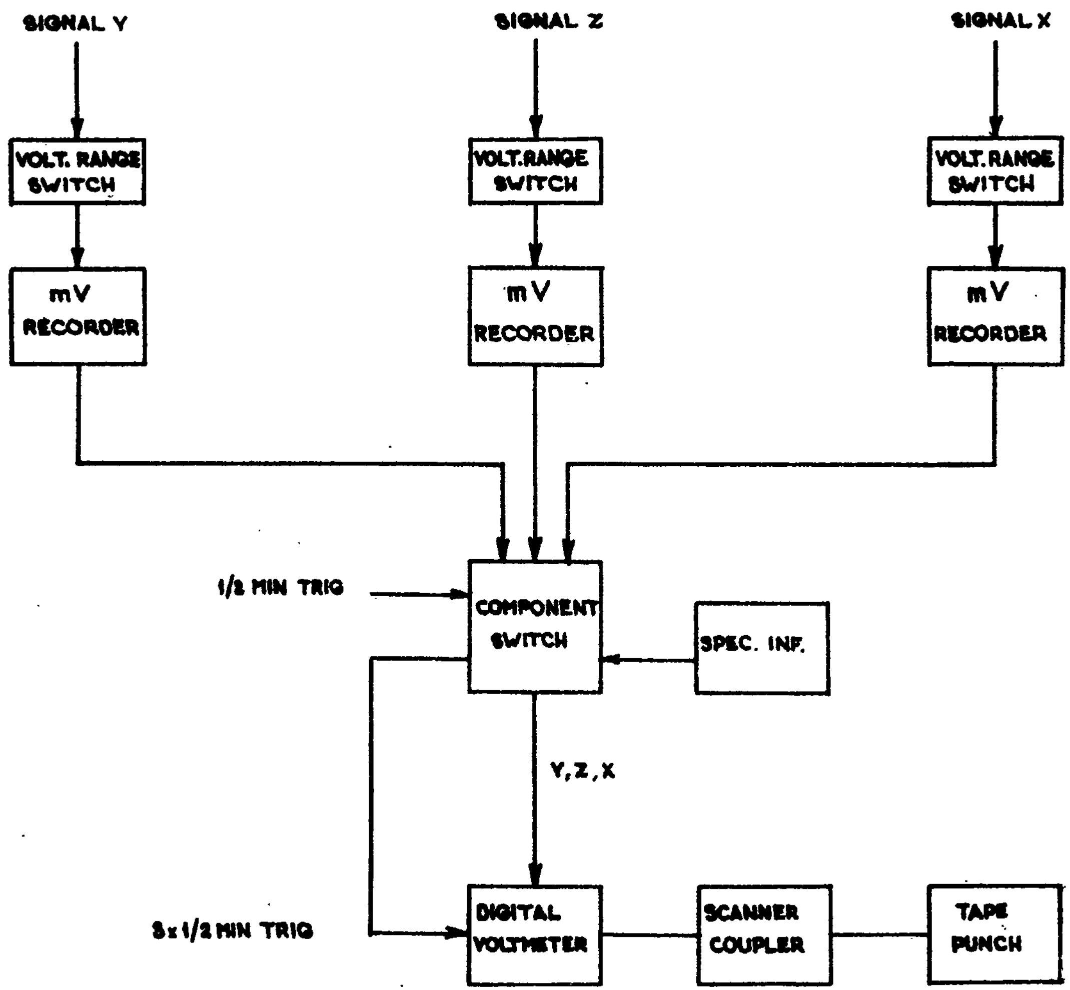

FIG 1. A schematic diagram of the equipment.

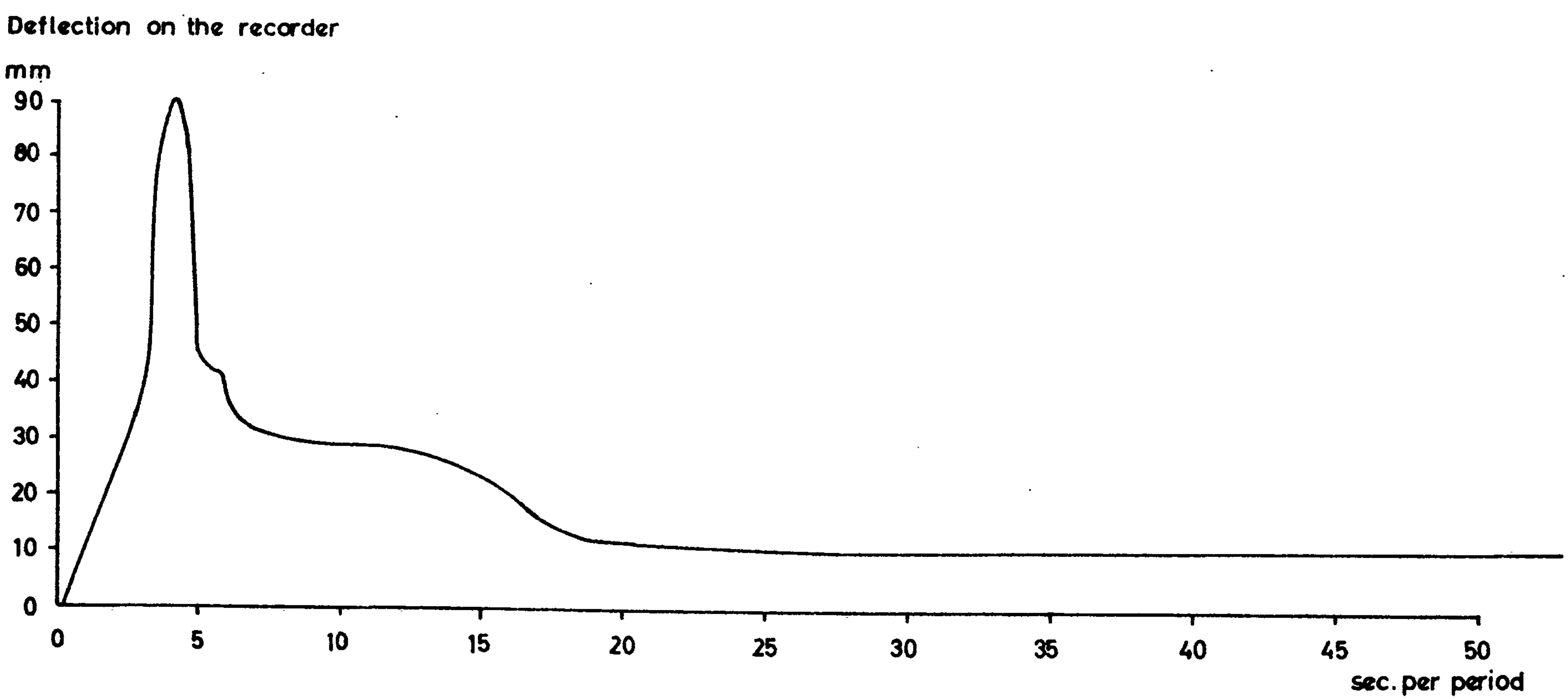

FIG 2. Frequency response of the higher frequency section of magnetic detector itself.

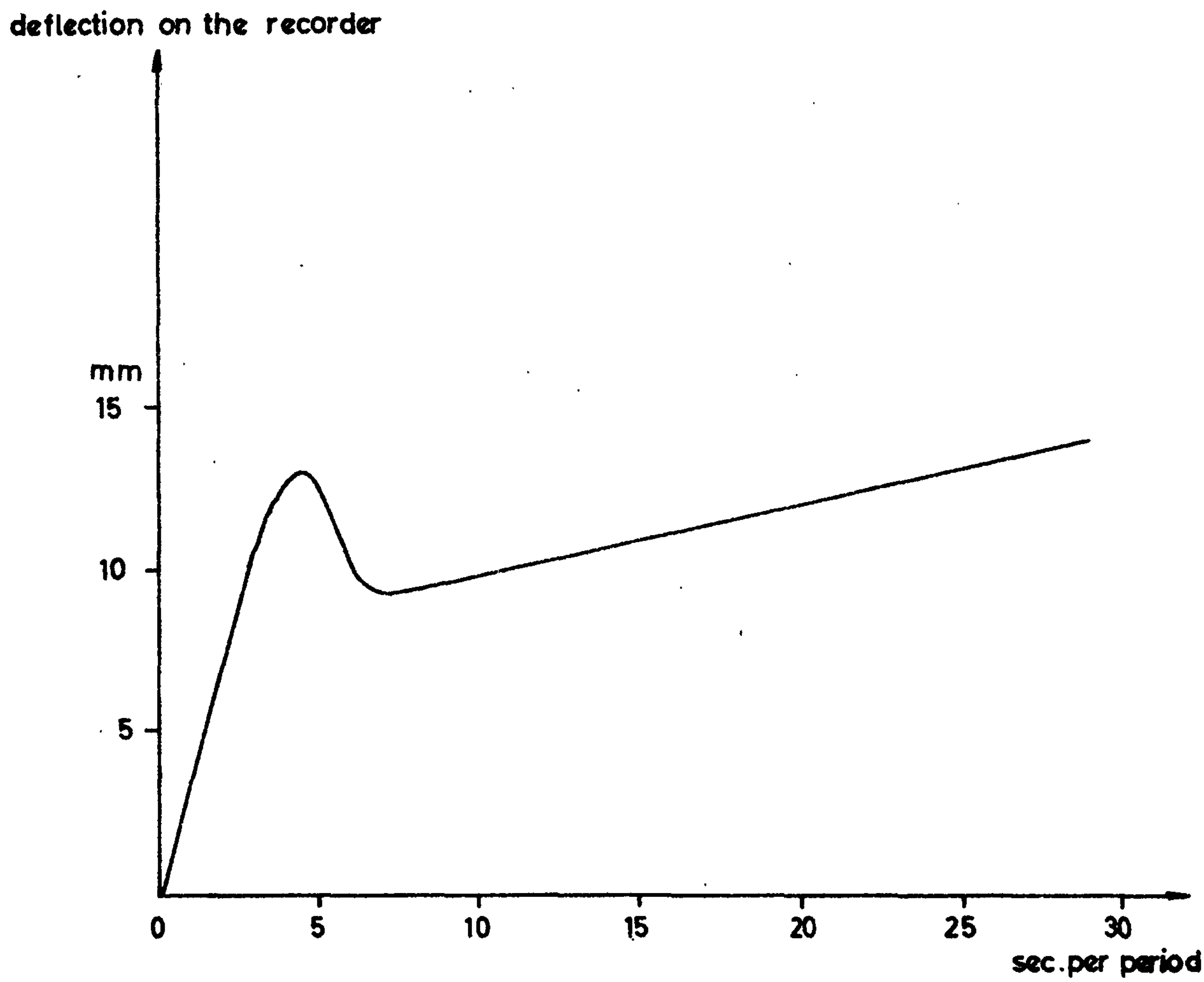

FIG 3. Frequency response curve for the whole recording system.

At the same time the measuring range of the system was divided in several parts by means of switches, which change the scale factor of the millovolt recorder when the deflection surmounts or falls below certain threshold values. In this way a higher accuracy in the measurements, especially for small variations, was achieved. At present the digital voltmeter reads 1.03 to 9.25 volts for -350 γ to +350 γ and if the disturbance is stronger than 350 γ the voltmeter switches to the range 16.3 - 65.8 volts, which corresponds to $\pm$ 2500 γ. Those values may be adjusted within rather small limits. It is also possible to have the measuring range divided in more than three parts.

The accuracy of the voltmeter reading with the arrangement described is approximately $\pm$ 0.8 γ, $\pm$ 5 γ and $\pm$ 20 γ respectively for the three different scale factors. The range switches were installed in March 1962 and have been working satisfactorily since then. The scale values for the respective ranges are 3.13 γ/mm, 9.3 γ/mm and 18.3 γ/mm on the recorder (or 85.23 γ/volt, 42.3 γ/volt and 208 γ/volt).

The voltage range swithches are shown in Fig. 4.

In the Philips recorder, 5 microswitches have been mounted, 2 in each extreme position of the recorder carriage A 11, A 12 and A 21, A 22 and one at the middle of the scale, Mk. All these switches are activated by the carriage of the recorder. The unit consists of a reversible 24 V motor, M, a transformer, T1. On the axis of the motor, M, a contact wheel is mounted which activates three microswitches MS 1, 2 and 3, and each of the switches is connected to a relay with several poles. Furthermore there is a contact wheel on the motor axis with the microswitch, Ms 4, which is connected to relay, R2.

In the normal case (range 1) the contact, Ms 1, is closed and the recorder is in its most sensitive position ($\pm$ 350 gammas). The voltage to the digital voltmeter is then between 1 and 10 Volts. In this position the carriage does not actuate the contact at the middle of the scale, Mk, and contact, Ms 4, remains open.

If the signal is strong enough to produce full scale deflection of the carriage, either A 11 and A 21, or A 12 and A 22, will be closed and the associated relay, R 1, will be energized. R 1 will remain closed due to the external voltage applied at the same time. The motor starts and stops when contact, Ms 2, closes.

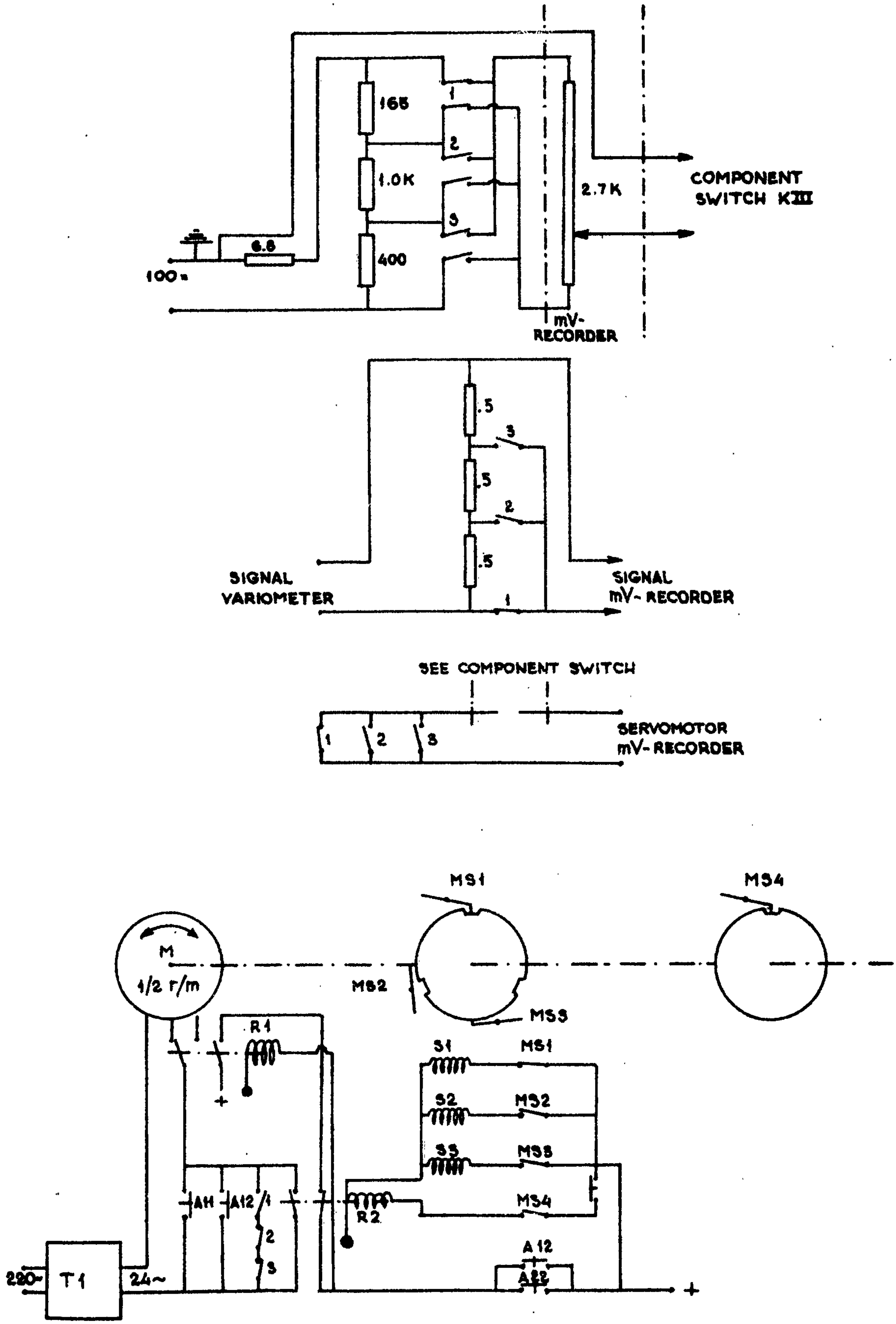

FIG 4. Voltage range switches.

At the same time the voltage range on the Philips recorder will be changed to $\pm$ 1000 gammas and the voltage to the digital voltmeter will lie between 10 Volts and 70 Volts.

During switching between ranges, when none of the contacts Ms 1, 2 or 3 are closed, the servo-motor is switched off in order to ensure that no erroneous value will be recorded. If the reading is made during the time of switching the value at the instant before switching off the servo-motor will be used. Now if the carriage returns to the center of the scale contact, Mk, will be closed and relay, R 2, will be energized, (contact, Ms 4, is closed at this moment). Relay, R 1, will be released, the motor connections changed, and the motor will return to its original position closing Ms 1. At the same time, the range on the recorder will also change. The operations between range 2 and 3 are similar to those described above. It takes approximately 10 seconds to change from one range to the other.

The details of the component switches are shown in Fig. 5.

This unit was built in order to have simultaneous sampling of all three components X, Y and Z, and to distribute the readings on the punched tape. One of the components (the vertical) will have negative voltage values. For this purpose a new voltage supply was procured (Oltronix LS/120R) which gives 1 negative and two positive voltages independent of each other. The earlier trigger unit, giving one pulse per 30 seconds starts a motor which controls a selector switch with three cams.
The voltmeter will be triggered twice for each of the components.
This is to ensure a correct reading even when two consecutive values are greatly different from each other. The punch is blocked during the first triggering action, by means of Cam K1.
The voltage supply forthe motor, M, is disconnected on every hour, in order to punch the "spec. information."
This means that only 119 values will be punched for each component during one hour. There is time for punching both the spec. information and the measured value during the first half minute of the hour, but it was not considered worth while to make a complicated system to include this value.
When the motor, M, starts, the voltage supply for the three servo-systems will be switched off at the same time, and no variations can occur during the time of sampling. This makes it possible to record the samples at

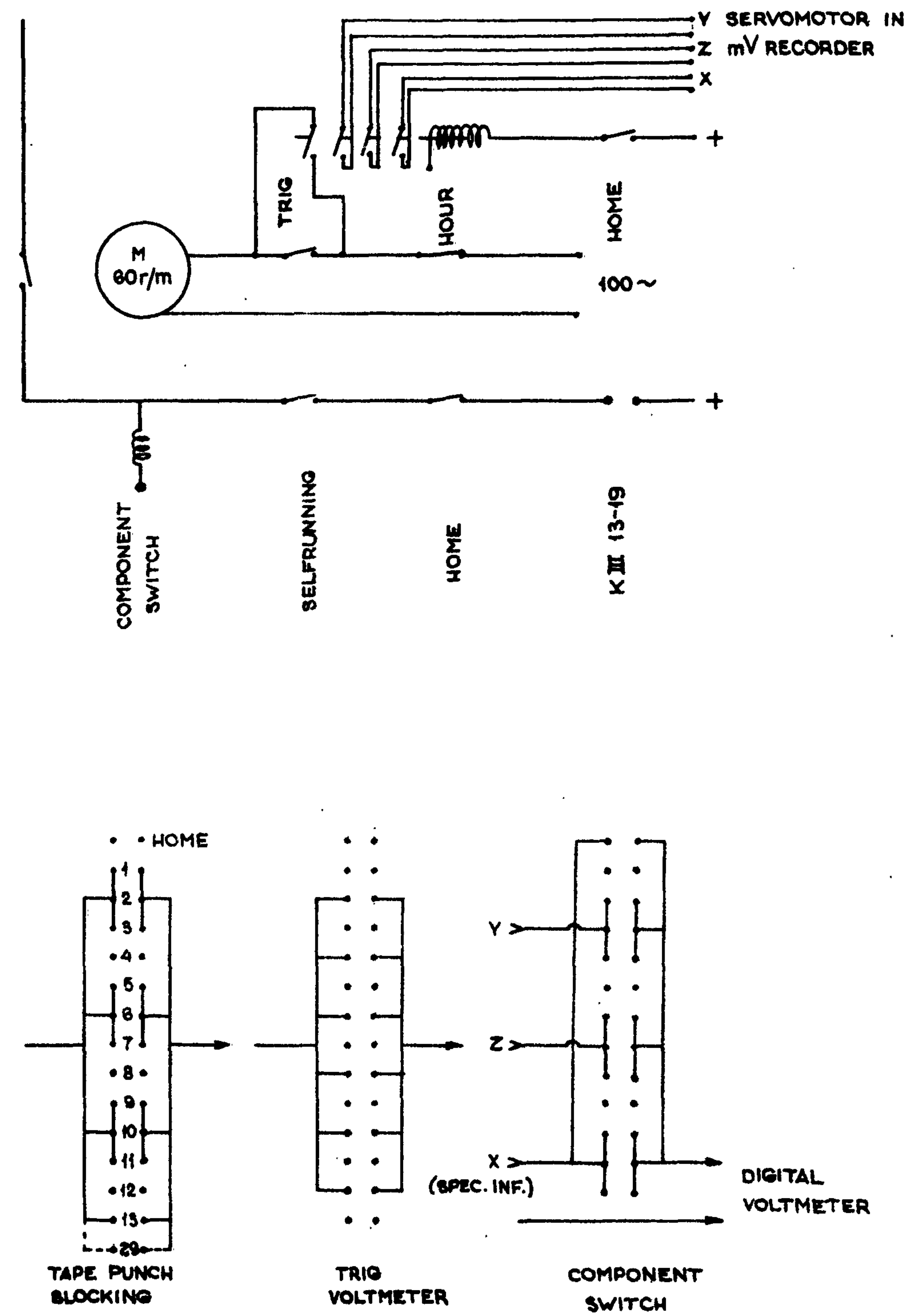

FIG 5. The switches for selection of the components X, Y, Z, and spec. information.

exactly the same time for all three components, which is very valuable because the disturbance vector can be calculated with good accuracy even during rapid variations of the magnetic field.

The AC-voltage regulator (Philips, Type 7776) has been replaced by a new type (Advance CVH1500A with filter), which has a minimum of active elements and appears to be more reliable.

An alarm has been connected to the punch unit to indicate when the tape is almost exhausted.

3. Reliability of the equipment

In the period during which the equipment has been in operation, the digital voltmeter has not given any trouble except that mentioned earlier concerning the decimal shift. The transducer and the transmission lines have performed correctly.

In the timing unit, one microswitch and one resistor have been replaced during the entire recording period of about two years. The reliability of this part has therefore surpassed all expectations. The faults which have occured in the scanner-coupler and the punching unit have been the most troublesome, due to their sporadic nature, and they have been difficult to locate. A relay in the scanner-coupler and a level arm in the punch have been replaced. The experience therefore is that special checks of the scanner-couplerand the punch are necessary. To enable an early detection of malfunction a read out system has been ordered. Spare units of both scanner-coupler and punch will be procured and at the digitally recording units in the equipment will, at certain intervals, be replaced by identical units which have been carefully checked with regard to reliability by running a calibrated signal through the system for a certain length of time.

4. Film recordings

Film recordings have been taken continuously since March 1962 on 70 mm Kodak film, in lengths of 100 feet. The film is removed every 19th day and developed.

A Hansen developer has been bought from Holland which has proved satisfactory for this film. The only troubles which have been experienced with the film recording equipment are that the light source and the igniter for this have had to be replaced.

II Reduction of data recorded by the automatic digital system for geomagnetic standard data

1. Description of principles and procedures

The equipment for automatic digital recording of geomagnetic standard data was designed to record only the X-component at first, but now has been redesigned to record the Y and Z components too. (see Hultqvist et. al. 1961). The transducer (magnetovariograph) and the analogue-digital converter have also been redesigned to a certain extent. Earlier the data was measured in one voltage-range but now three different voltage-ranges are used. This extension of the system has caused the earlier stated orientation with regard to the automatic data processing of the geomagnetic standard data to be partly revised, and the computer-program has been completely revised.

The modifications regarding the program will be described and the main principles in the new computer-system will be shown by flow diagrams. The flow diagrams presented in Figs. 6, 7, 8 and 9, show only the chief outlines in the computations. Some of the controls and checks on the evaluation-process will be seen. The presentation of the final results will also be given.

The essential differences are as follows:

a) For technical reasons it proved necessary to use at least three different voltage-ranges when recording the geomagnetic data. This gives rise to extended demands upon the storage-space available in the internal storage. In order to prepare the computer-program for any modifications in this respect, the storage space has been reserved for five alternative voltage-ranges for the X-, Y- and Z-components, respectively.

b) This technique with alternative voltage-ranges in the recording system means that most checks in regard to the reasonableness ot the recorded values have to be performed in the program after the individual magnetometer-data have been converted over to the unit "gammas". Earlier the data-checking could be carried out on the "raw" magnetometer-data. Naturally enough this fact will influence the computing time negatively. The first part of the computations will require approximatley 40 % longer time. At present the time consumption will be 45 - 50 sec for one hour of data consisting of 120

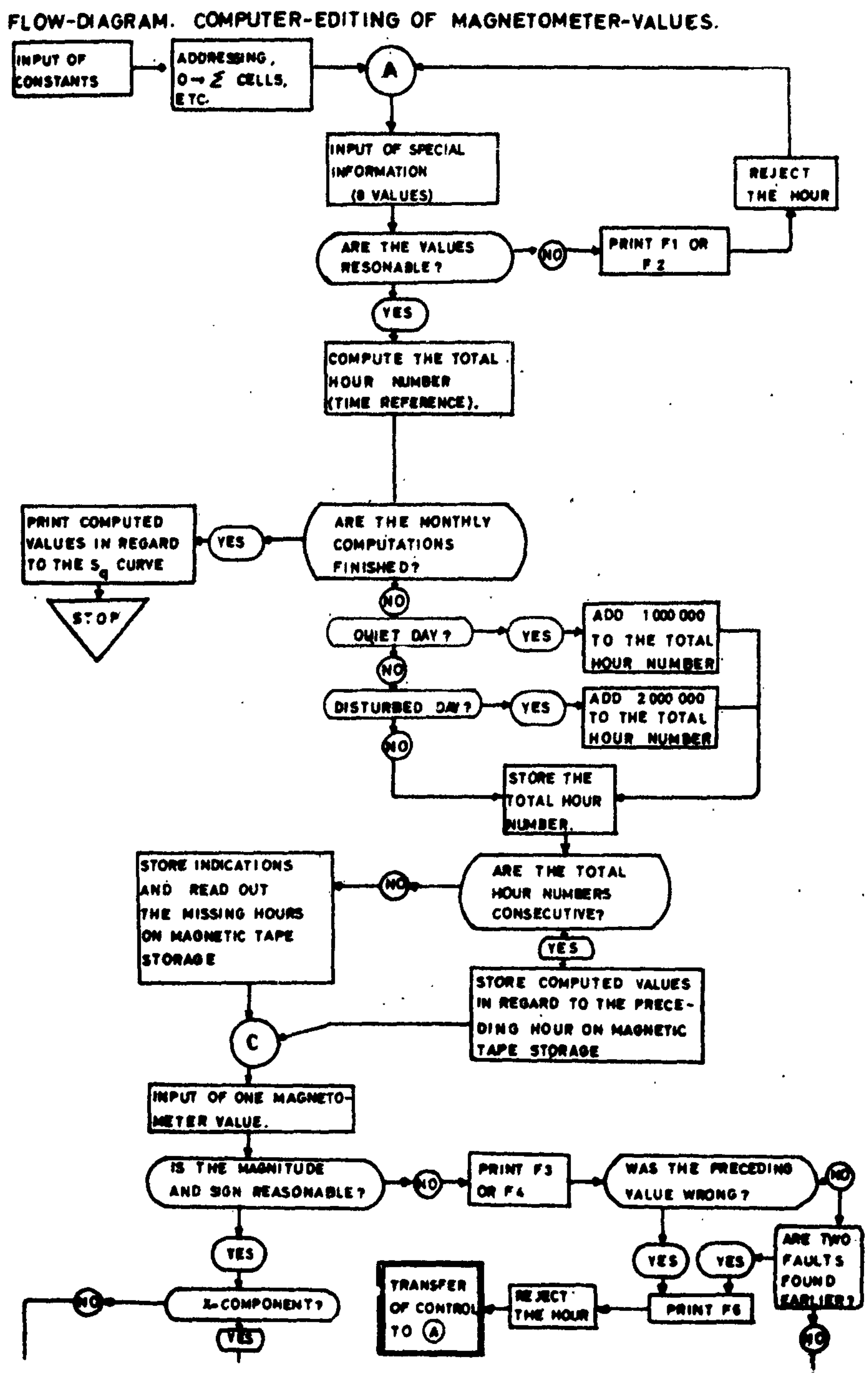

FIG 6. Abridged flow diagram, part 1a.

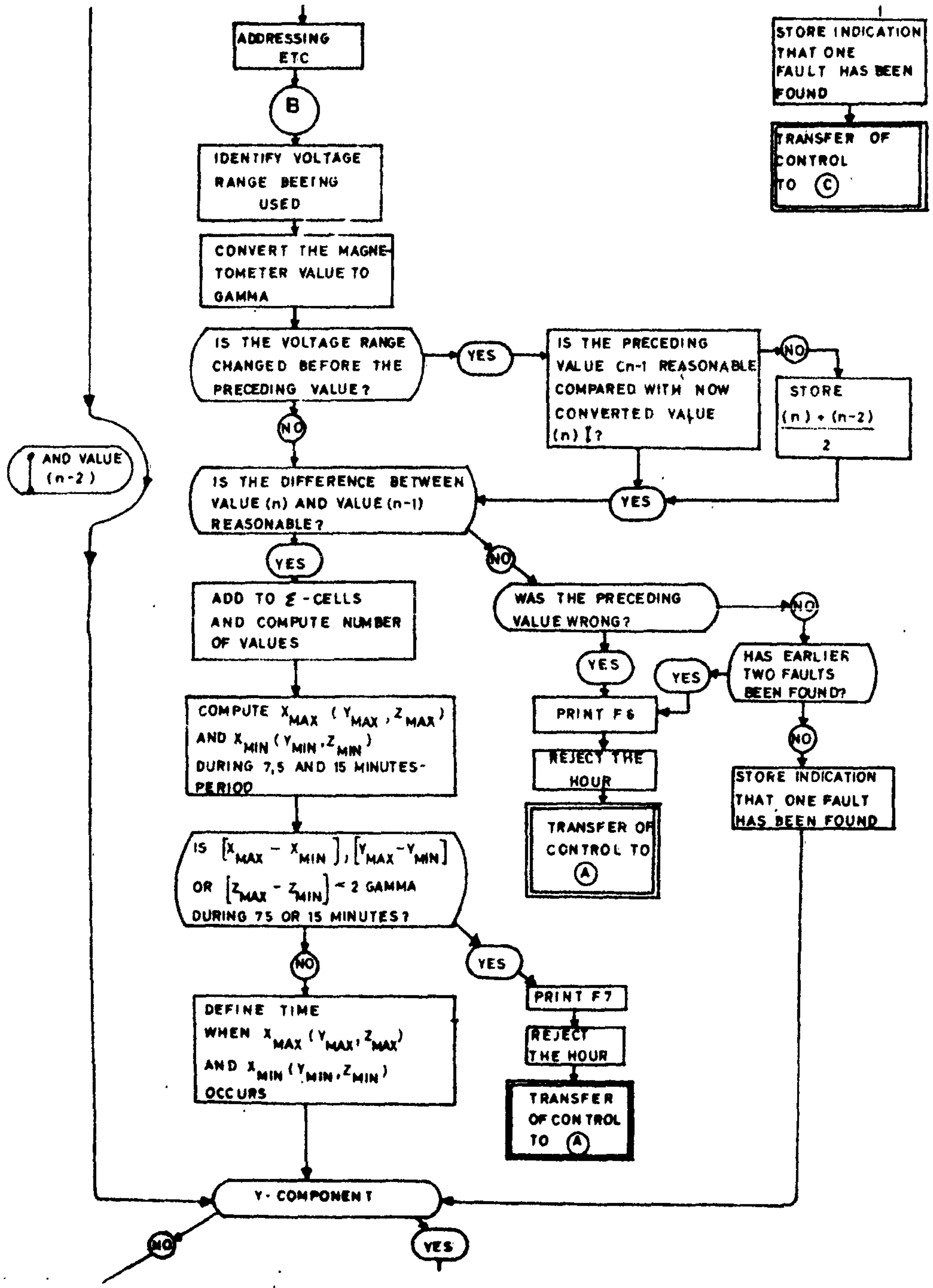

FIG 7. Abridged flow diagram, part 1b.

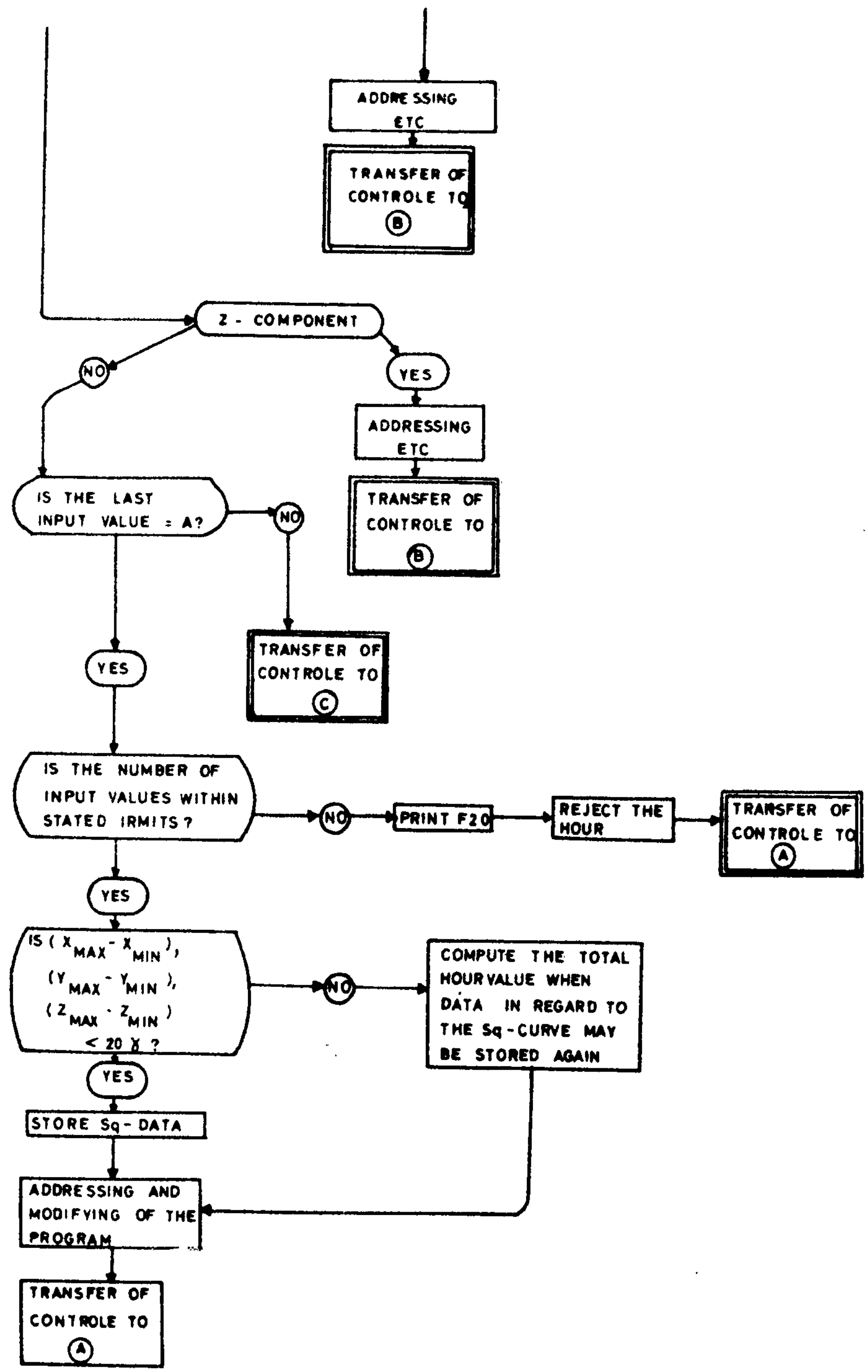

FIG 8. Abridged flow diagram, part 2.

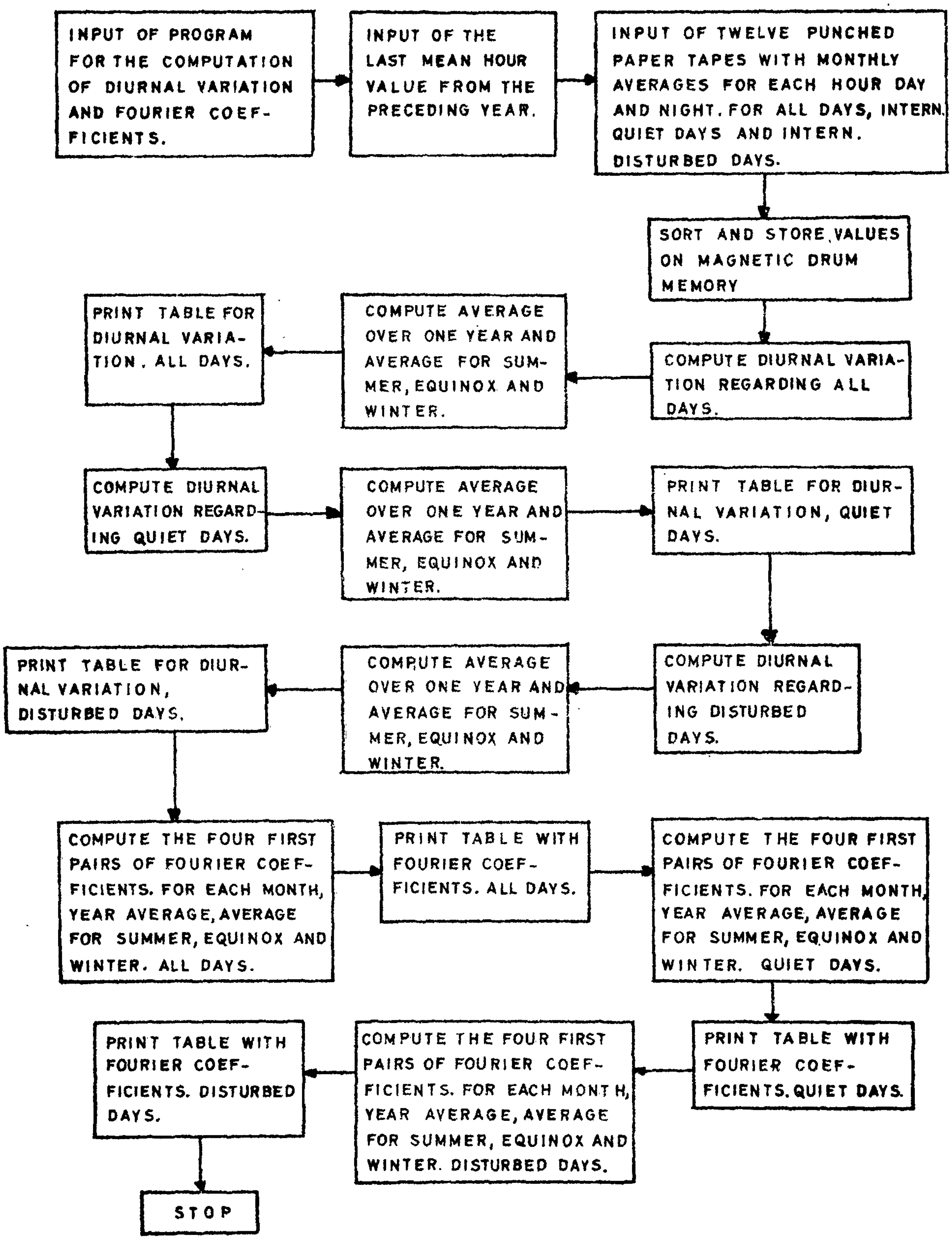

Fig. 9 A bridged flow diagram, part 3.

magnetometer-values; that is, less than half a second to convert one value to "gamma" and to perform the controls necessary. The possibility of diminishing this computing-time seems to be limited, as the program, as far as possible, is written in pure machine code. When the Y- and Z-components are added, the computer-time will increase roughly three times.

c) The new version of the data reducing system contains a special sequence for defining the S_q-curve. The S_q-values are taken into consideration when computing monthly and yearly tables.

d) The output regarding the monthly tables is almost unaltered. The Q- and K-index numbers, however, required a complete reprogramming, as the characters in these tables are dependent on a comparison with the X, Y and Z indices.

e) The earlier planned division of the computer program into three different parts, has, for storage-space-reasons, been altered to a division into four parts. The first and rather small program (cf. Fig. 6) is solely designed for the input of constants necessary for the computations.

f) Values with the order numbers 5 and 6 in the special information now identify the number of magnetometer-registrations recorded during one hour and the actual combination of X-, Y- and Z-components.

The above mentioned modifications of the conditions for the data reducing system has occasionally caused the internal storage to be filled up with data and instructions. In connection with various check-computations, errors in the instructions were found. With reference to the maximum limited spare-space available in the internal storage, it has proved very difficult to introduce the necessary corrections without overflow in the storage. In same cases the program proved to be just a few instructions too long. The analysis to find other sequences or routines which might consist of fewer instructions, without introducing new errors, is rather time-consuming. It must be looked upon as motivated by a desire for a computer program which keeps all instructions and constants in the internal storage. If the program makes use of any external storage for such quantities as the computation-constants, the machine-time necessary for the computations will increase considerably.

In Fig. 10 a print out from a part of the magnetic tape storage, on which the computed data are stored, is shown.

The tables of the first Kiruna Geophysical Observatory year-book will, according to the present form of the computer program, contain the following parameters.

a) In monthly tables with dates in the vertical direction and hours in the horizontal: Hourly average values for the components; daily averages; maximum and minimum values for each day; the times of their occurrence and the differences between them; international quiet and disturbed days; monthly averages for each hour of the day and night; total hourly average for the month; averages of the international quiet days in each month, for each hour of the day and night; averages of the international disturbed days in each month, for each hour of the day and night; total average for the international quiet days in each month; total average for the international disturbed days in each month.

b) In monthly tables with dates in the vertical direction and hours in the horizontal: Q-indices for each quarter of an hours; daily averages of the absolute value of the difference between successive sampled values; daily averages of the absolute value of the difference between successive hourly averages of the components; for each day the quotient of the daily average of the difference between successive sampled values; magnetic daily character figures, C; magnetic K-indices monthly averages of the daily averages of the absolute values of the difference between the successive sampled values, - for all days, for international quiet days, and for international disturbed days; monthly averages of the daily averages of the absolute values of the difference between the successive hourly averages, - for all days, for international quiet days, and for international disturbed days; monthly averages of the daily quotients of the daily averages of the differences between successive hourly averages and the daily averages of the differences between successive sampled values, for all days, for international quiet days, and for international disturbed days; monthly averages of C figures for all days, for international quiet days, and for international disturbed days.

A0002

6553

080	666400008D	4F6EBA8595	5511159B8E	54D377808E
088	54D6E3D78E	545D5DCC8E	550BF3188E	5435FFE58E
090	553A29AD8E	549945BB8E	54DF72B08E	52E31A518E
098	553A29AD8E	0000000058	52E31A518E	0000000078
0A0	BB89376089	7B3C35F08A	7800000087	8000000000
0A8	0000000078	0000000000	666400008D	0000000000
0B0				
0B8				
0C0				
0C8				
0D0	0000000000	8000000000	0000000000	0000000000
0D8	666400008D	0000000000	0000000000	0000000000

Fig. 10 Print out of magnetic tape storage.

DESCRIPTION OF THE READ OUT FROM THE MAGNETIC TAPE

Fig. 10

A0002				
080	1	2	3	4
088	5	6	7	8
090	9	10	11	12
098	13	14	15	16
0A0	17	18	19	20
0A8	21	"	22	"
0B0	"	"	"	"
0B8	"	"	"	"
0C0	"	"	"	"
0C8	"	"	"	"
0D0	"	"	"	"
0D8	23	"	"	"

1 Reference time (total hour number counted from the beginning of the year)

2 $\sum X$

3 X_{max} During time (0 - 7.5 minutes)

4 X_{min} " "

5 X_{max} " (7.5 - 22.5 minutes)

6 X_{min} " "

7 X_{max} " (22.5 - 37.5 minutes)

8 X_{min} " "

9 X_{max} " (37.5 - 52.5 minutes)

10 X_{min} " "

11 X_{max} " (52.5 - 60.0 minutes)

12 X_{min} " "

13 X_{max} " (0 - 60 minutes)

14 Time when X_{max} occurs

15 X_{min} During time (0 - 60 minutes)

16 Time when X_{min} occurs

17 $\sum |\Delta X|$

18 $\sum \Delta X$

19 Number of approved magnetometer values

20 Identification in regard to approved hour, rejected hour or hour without any magnetometer-registrations

21 Total number of magnetometer values

22 and 23 Reference time. Y- and Z-components

c) In a yearly table for all days, with months in the vertical direction and hours in the horizontal:
differences between the total monthly averages and the corresponding monthly averages for each hour; yearly averages of the abovementioned difference for each hour of the day and night; averages for the summer-months of the above mentioned differences for each hour of the day and night; averages for the equinoctial months of the abovementioned differences for each hour of the day and night; averages for the wintermonths of the abovementioned differences for each hour of the day and night; total yearly average for all hours of the day and night; total equinoctial months average for all hours of the day and night; total winter months average for all hours of the day and night.

d) In a yearly table, for international quiet days only, with months in the vertical direction and hours in the horizontal:
The same parameters as under c.

e) In a yearly table, for international disturbed days only, with months in the vertical direction and hours in the horizontal:
The same parameters as under c.

f) In a yearly table of the first four pairs of Fourier coefficients for all days, international quiet days and international disturbed days, with months in the vertical direction and the coefficients in the horizontal (to the left for all days, in the middle for international quiet days, and to the right for international disturbed days):
The four first Fourier coefficients for each month;
" " " " " " the whole year;
" " " " " " the summer months;
" " " " " " the equinoctial months;
" " " " " " the winter months;

Finally it should be pointed out, that 1) no external storage will be used during computations 2) the program is now working correctly in its main parts. The number of remaining errors must be very limited. Thus it seems to be possible to make the data reduction system work properly within the near future.

The program has been made rather general. It includes e. g. five different voltage-ranges for each component. The spec. information includes the number of components which are recorded, and how many values each component contain per hour. This means that it is possible to change the punching speed during periods which are of special interest. As will be discussed in Section III a computer program has also been made for the calculation of power spectra.

It has also been planned to make a special program to calculate the magnetude and the direction of the disturbance vector.

III A statistical study of the fine structure in geomagnetic recordings

1. Introduction

A statistical analysis was made of the X-component of the earth's magnetic field. The main purpose of this investigation was to develop the technique and program for the computations and to find out the maximum frequency at which it is possible to use the equipment, considering its limited sensitivity.

A special case, that of a magnetic storm, was also studied and compared with auroral and ionospheric absorption data.

2. Method of analyses

Equi-spaced data samples were selected during different magnetic situations and the variance (power) spectrum was evaluated by statistical methods. A Fourier transformation was made of the autocorrelation function of the recorded amplitude variation. The autocorrelation function was calculated according to the formula

$$r_h = \frac{\sum X_i X_{i+h} - \frac{\sum X_i \sum X_{i+h}}{N-h}}{\left[\left(X_i^2 - \frac{(\sum X_i)^2}{N-h}\right)\left(\sum X_{i+h}^2 - \frac{(\sum X_{i+h})^2}{N-h}\right)\right]^{1/2}}$$

where i = 1, 2, 3, 4. . . . . , N-h.

The mean lagged products were adjusted by the mean and normalized. The coefficients were computed for lags from 0 to m.

Next, the finite cosine series transform was calculated from the Equation

$$B_n = \frac{r_o}{m} + \frac{2}{m} \sum_{h-1}^{m-1} \left(r_h \cos \frac{\pi hn}{m}\right) + \frac{r_m}{m} \cos n\pi$$

In the cases B_o and B_m, the coefficients resulting from the formula have to be divided by 2. If B_n is plotted as a function of $\frac{n}{2m\Delta t}$ (Δt is the time spacing between the data values) the resulting curve is a smoothed version of the normalized spectrum of the original series.

The bandwidth of the estimates is given by $\frac{1}{m\Delta t}$. The smaller m is, compared to, the original number of observations, the more smoothing is obtained. But when m becomes small little will be known concerning the importance of long periods, since $2m\Delta t$ is the fundamental period.

Furthermore, small m decreases the resolution of the technique.

Some of the weights are negative in the above formula and this will result in a distortion of the spectral estimates whenever rapid fluctuations occur in the true spectrum. To overcome this difficulty, the coefficients have been smoothed by a weighted moving average, a spectral window with small side lobes (cf. Blackman and Tukey, 1959) according to the following formulas:

$$S_o = 0.5\, B_o + 0.5\, B_1$$

$$S_n = 0.25\, B_{n-1} + 0.5\, B_n + 0.25\, B_{n+1}$$

$$S_m = 0.5\, B_{m-1} + 0.5\, B_m$$

If the spectrum to be determined is expected to be reasonably flat, the amount of the data required can be determined (cf. Blackman and Tukey, 1959) by the following expression (total duration of record, in

$$\text{seconds}) = \frac{0.5 + \left(\frac{125}{80\%\ \text{range in dB}}\right)^2 + \frac{\text{pieces}}{3}}{(\text{resolution in cps})}$$

If for example, a resolution of $8.45 \cdot 10^{-4}$ cps is to be obtained from one piece of record and is to furnish stability of $\pm$ 2 db for (on the average) 8/10 of the individual estimates, then the necessary duration will be 10200 seconds.

As the frequency cut off for the instrumentation was about 0.5 cps it was necessary to use a punching speed of one per second in order to resolve that frequency while in order to obtain sufficient resolution, 3 hour samples were used. Two such samples were analysed down to a frequency of $4.2 \cdot 10^{-4}$ cps and the result is shown in Fig. 10. The highest frequency obtainable with this technique is 0.5 cps, which value is determined by the maximum punching speed.

They were selected during a period of low magnetic activity, but pulsations could be seen with amplitudes of up to 30 γ.

It was found from the measurements, described above, the spectrum of the magnetic variations decreased rapidly with increasing frequency and that no variations at all could be identified for frequencies above 0.01 cps (the fluctuations were very small above 0.005 cps) from the two samples analysed. For this reason a punching speed of 30 seconds

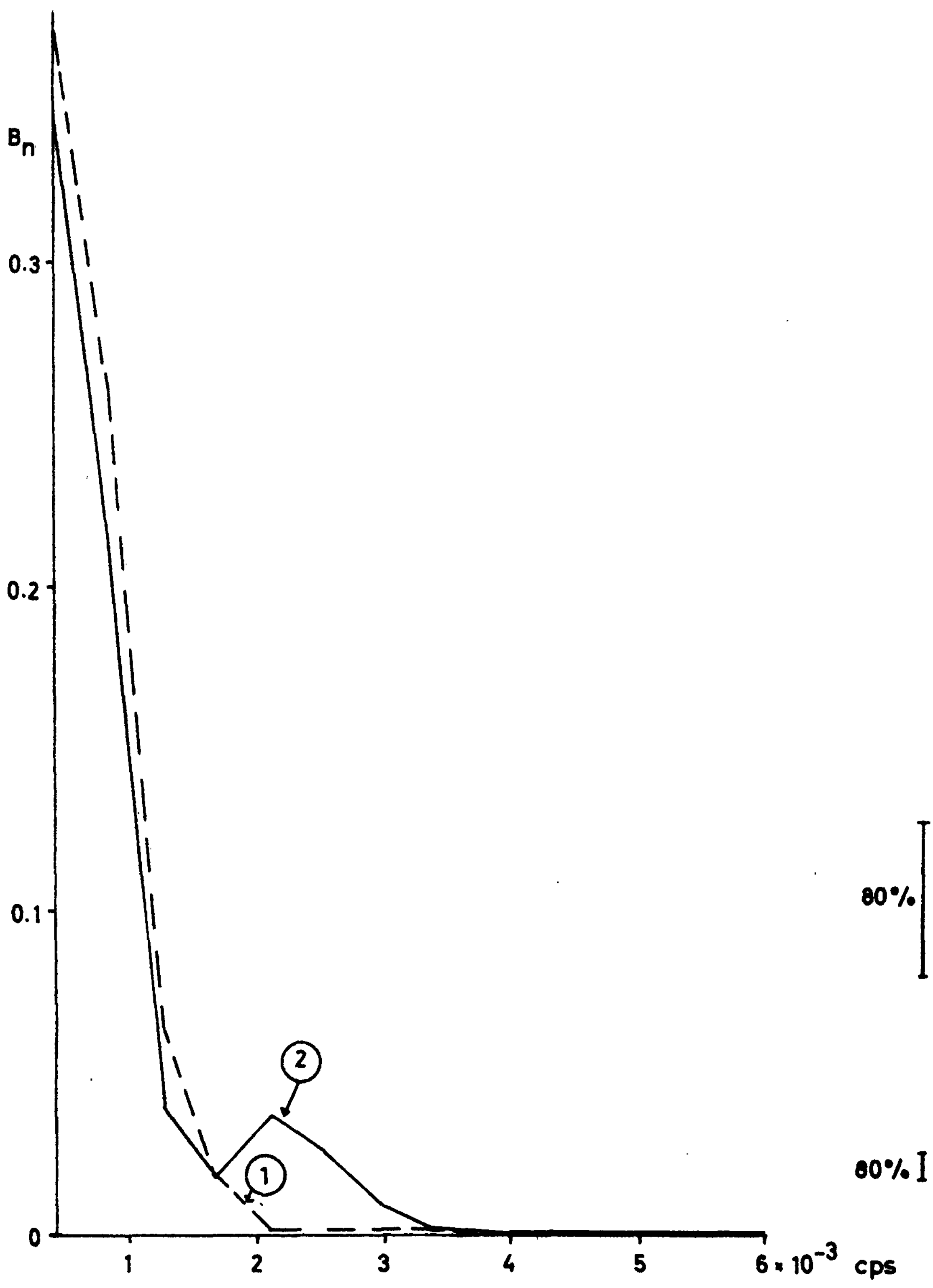

Fig. 11 Power spectrum of the magnetic variations, the uncertainty is indicated to the right.

per punch can be used which is the normal speed for the equipment.

To be able to compare the result with other geophysical parameters it is desirable to take data samples as short as possible. A compromise has to be made between the lowest frequency which can be analysed and the length of the sample that can be accepted. In this case four three-hour samples where chosen which gave a reasonable resolution (approximately $3 \cdot 10^{-3}$ cps) down to a frequency of $2.0 \cdot 10^{-3}$ cps. The spectra are shown in Fig. 12.

The following notations have been used: 0500 - 0800 No. 1, 0800 - 1100 No 2, 2000 - 2300 No 3 for the data from October 9, 1962. The fourth sample starting at 2300 did not give any contribution at all to the spectrum within the frequency interval which was analysed.

3. Results obtained from the data

From the quick-punch data (one punch per second) it was found that during the selected periods with strong pulsations on the normal run magnetogram, no contribution could be found to the spectrum above 0.01 cps. Before smoothing of the spectrum, some variations occurred up to 0.02 cps. This means that the sensitivity of the equipment (about one gamma) is too low for spectrum analyses below about 0.01 cps, although, in extreme cases, variations of higher frequency than this may occur.

Fig. ''.indicates that the majority of the variations occur at frequencies below about $1.5 \cdot 10^{-3}$ cps and that a peak in the spectrum sometimes occurs at higher frequencies, in this case at about $2.2 \cdot 10^{-3}$ cps.

In order to investigate the enhancement of the spectrum between $1 \cdot 10^{-3}$ and $5 \cdot 10^{-3}$ cps, four three-hour-samples were chosen during a day with strong magnetic variations (cf. Fig. 12).

From the spectra of the samples taken on October 9, magnetic variations with a frequency of about $4 \cdot 10^{-3}$ cps can be seen to have occurred during samples 1 and 2, but these had dissappeared later in the day during the main phase of the storm (samples 3 and 4).

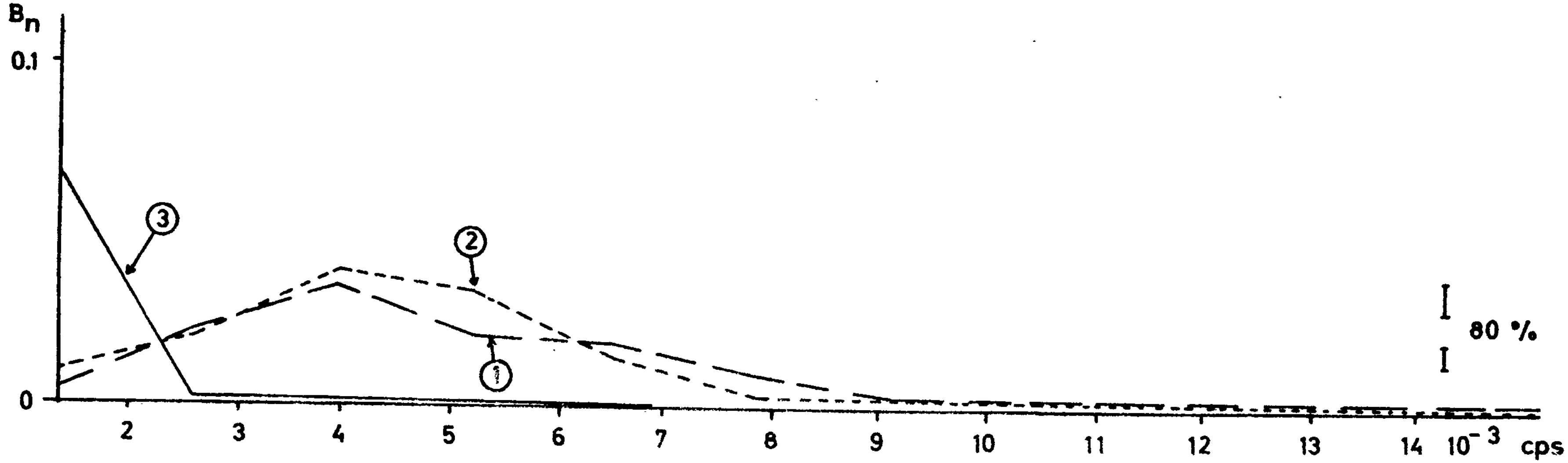

Fig. 12 Power spectrum of the magnetic variations (notations see text).

In the late evening of October 9 very bright aurorae and auroral type absorption were recorded, which indicates that the peak in the magnetic spectrum is not directly connected to magnetic disturbances caused by aurora.

Evidence of low frequency hydromagnetic waves in the exosphere, in the frequency range which has been analysed here, have been given by eg. Sugiura (1961). He found that damped waves occurred in the auroral zone with a duration of approximately 0.5 hours and with amplitudes of up to one hundred gammas. With the technique described above it will be possible to obtain spectra for selected periods which show damped waves with a resolution of $2 \cdot 10^{-3}$, from e.g. 11 half-hour samples or from three-hour samples as mentioned earlier.

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10 April 1963
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A computer program has been developed for the reduction of the data.
An analyses has also been made of the spectrum of the fluctuations of the geomagnetic X-componentinthe frequency range $0.5 - 4.2 \cdot 10^{-4}$ cps.

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